ITk Layout Simulation

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Introduction

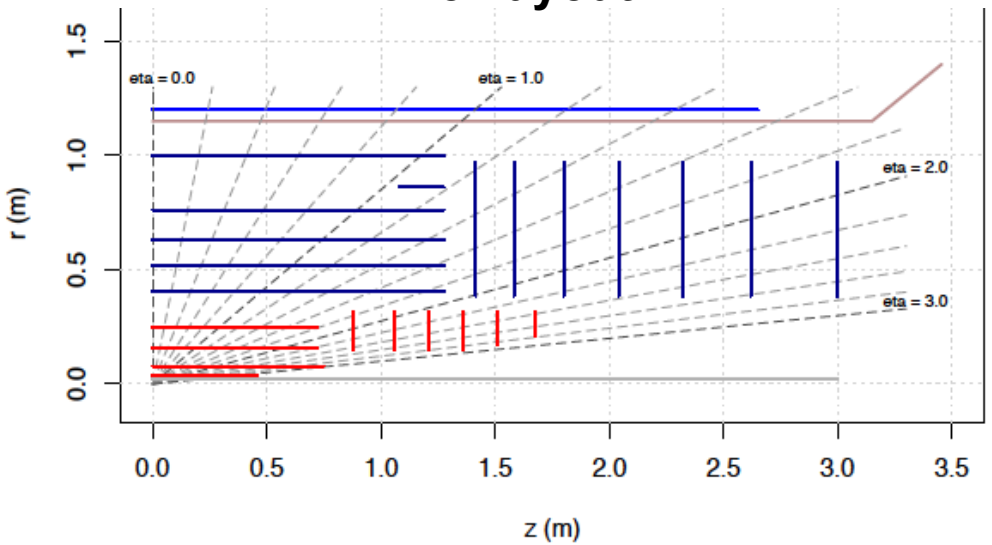
- Currently a lot of ongoing activity on the **ITk layout simulation** front
  - Still at the exploration stage, convergence process expected to start this autumn
- Outline:
  - Letter of Intent layouts (LoI and LoI-VF)
  - Phase-II upgrade scoping exercise
  - Number of pixel barrel layers, and boundary between pixel and strip detectors
  - Specific design ideas
    - Inclined modules concept
    - Strip stereo angle studies
    - Pixel endcap rings
  - Extended tracking η coverage
    - Large-η Task Force results
    - Extended inner pixel barrel layers

Letter of Intent layouts

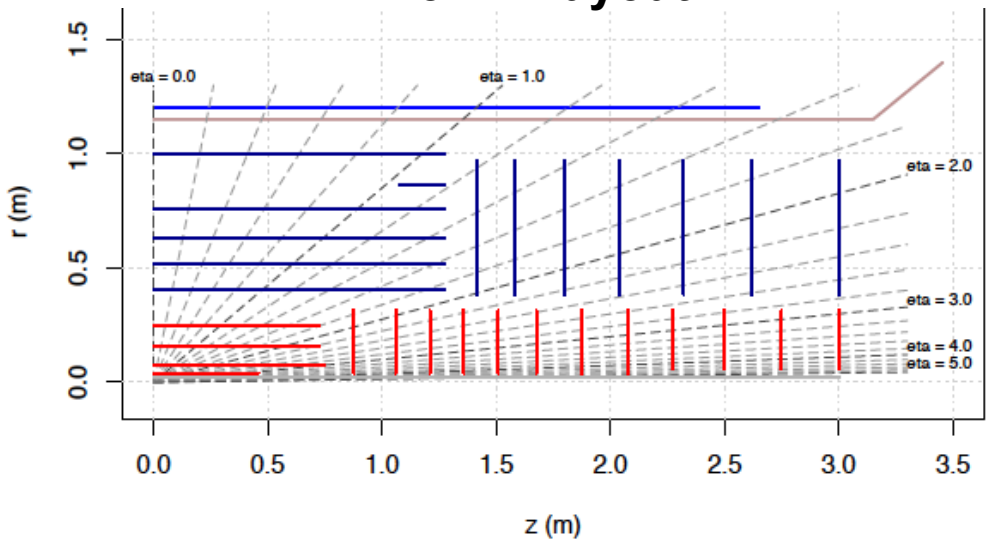
Layout Task Force

- The ATLAS Phase-II **Letter of Intent** (LoI) defined an **ITk layout** in 2012
  - Not a candidate for construction
  - Still used in full simulation for many Phase-II upgrade studies
- A **very-forward** layout was created, simply by extending the pixel disks
  - Unrealistic, no room for pixel services
  - Study impact on physics results of extending the tracking coverage up to **|η| = 4**

LoI layout



LoI-VF layout

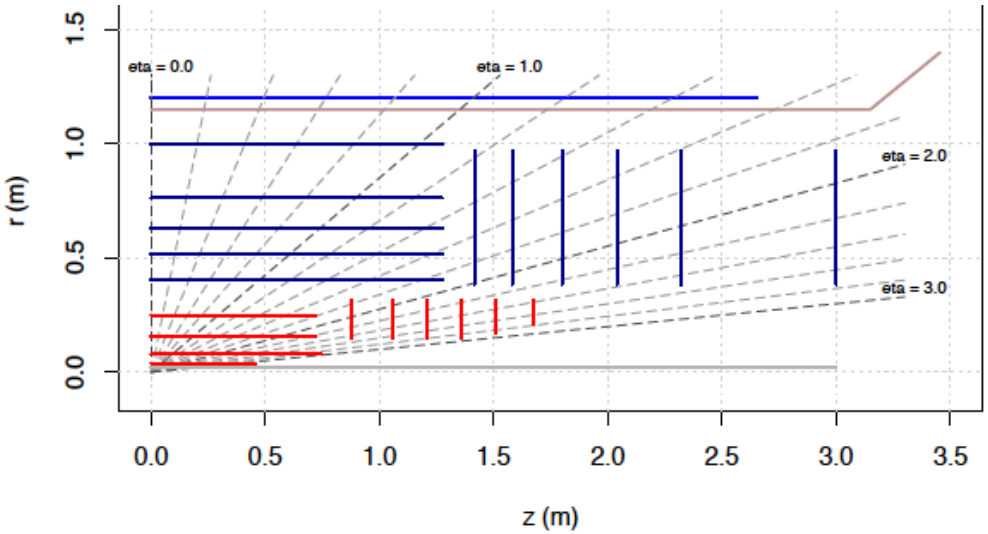


Scoping exercise

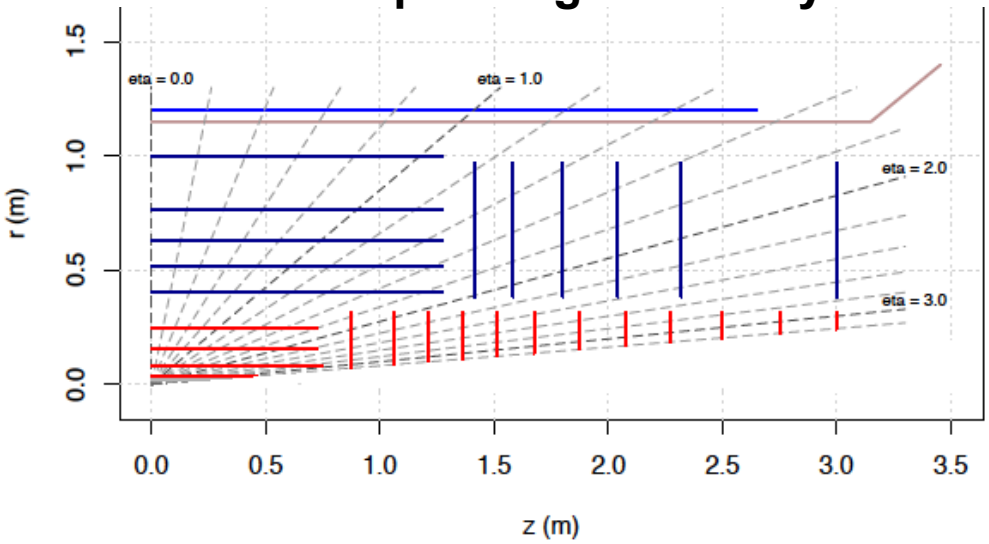
Layout Task Force

- Upcoming decision about the Phase-II upgrade budget
  - Balance physics performance against price
  - **200, 235 or 275 MCHF**, and ITk is about 50% of the cost
  - Actually a de-scoping exercise, as the LoI layout is a 275 MCHF scenario
    - But we can do better by re-designing for a given budget
  - Foreseen **MCHF → |η| coverage**: 200 → **2.7**, 235 → **3.2**, 275 → **4.0**

LoI layout (235 MCHF)



... corresponding LoI-VF layout



Full simulation results **expected soon**

Scoping exercise

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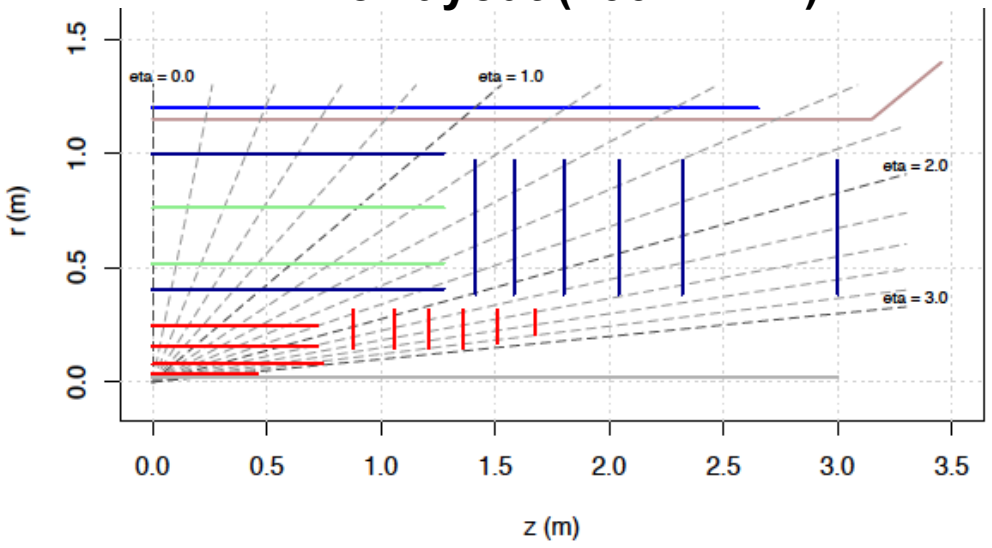
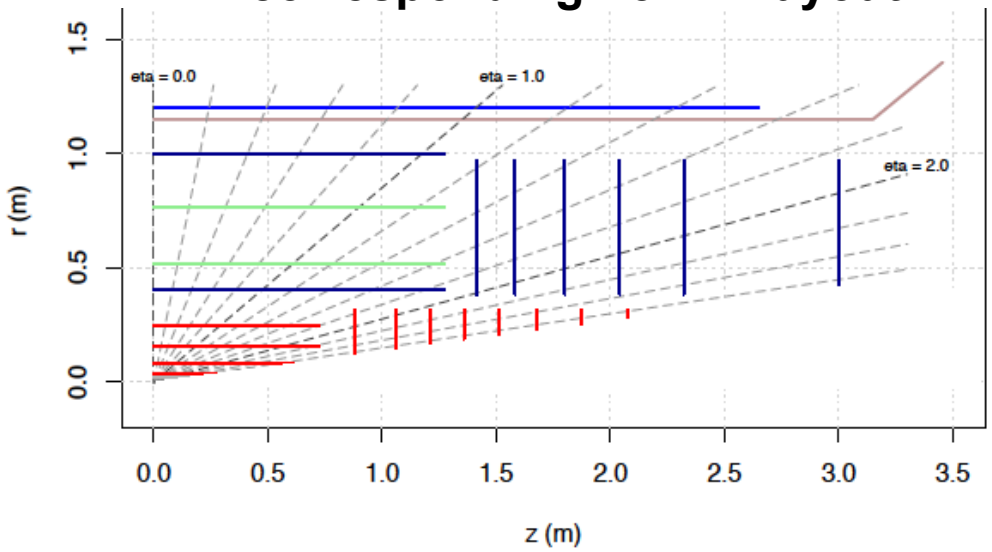
LoI layout (200 MCHF)



Here green strips means single-sided (not stereo)

... corresponding LoI-VF layout



Full simulation results **expected soon**

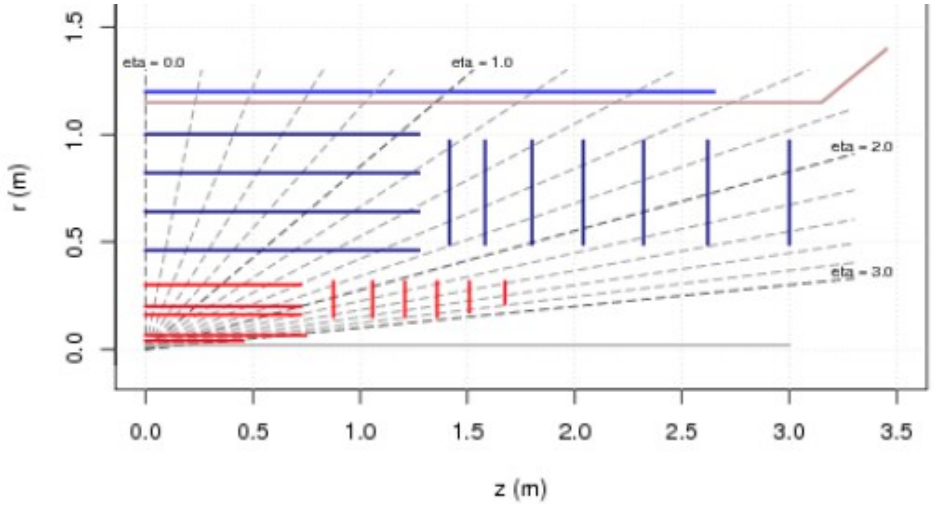
Number of pixel barrel layers

and boundary between pixel and strip detectors

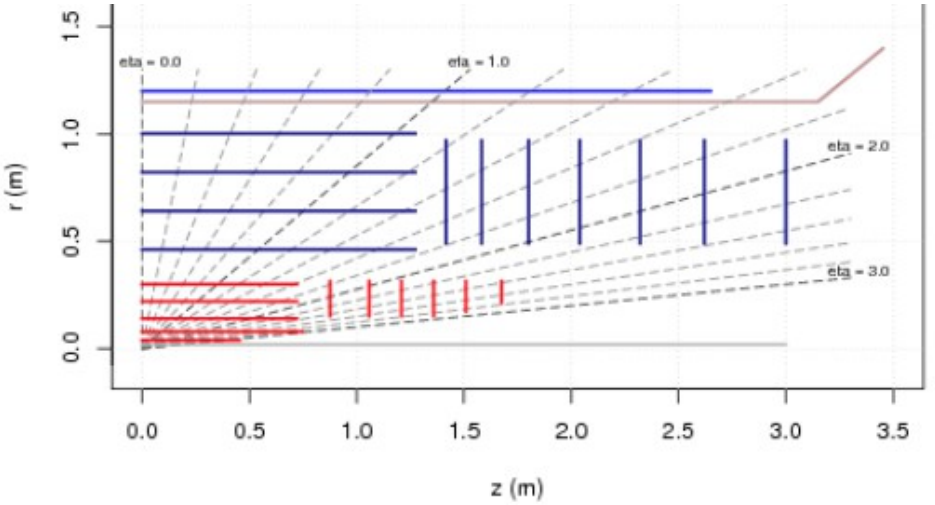
Number of pixel barrel layers

Layout Task Force

- Idea to increase the **number of pixel barrel layers to 5 or 6**
  - Studies with 4 double-sided strip barrel layers (no more stub), and shortened disks
  - This number can impact the whole ITk layout design
- Two fully-simulated layouts with 5 pixel barrel layers:



Pixel 5A



Pixel 5B

- Barrel layer **"doublets"**

  R = 39, 65, 160, 200, 300 mm

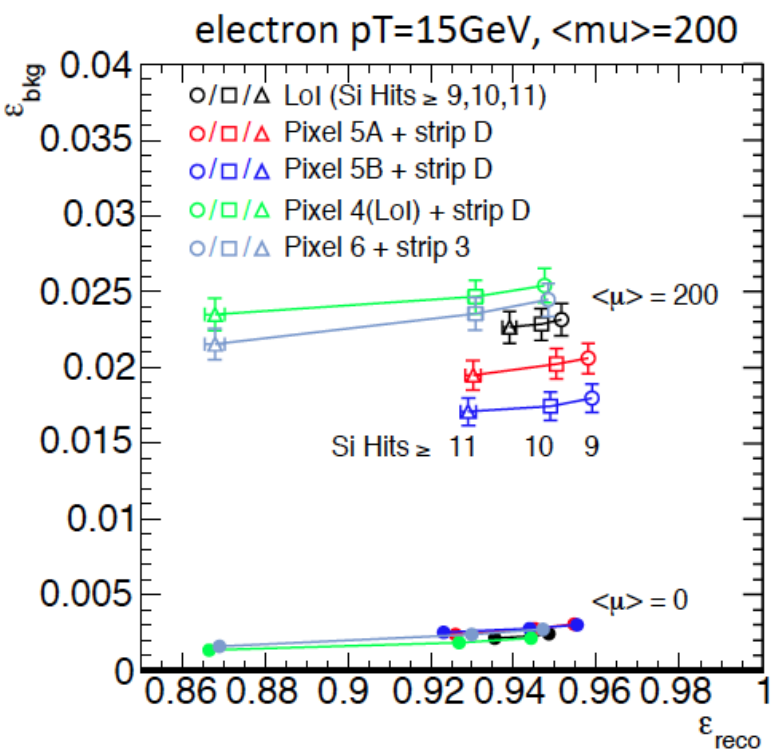
- Barrel layers **"equidistant"**

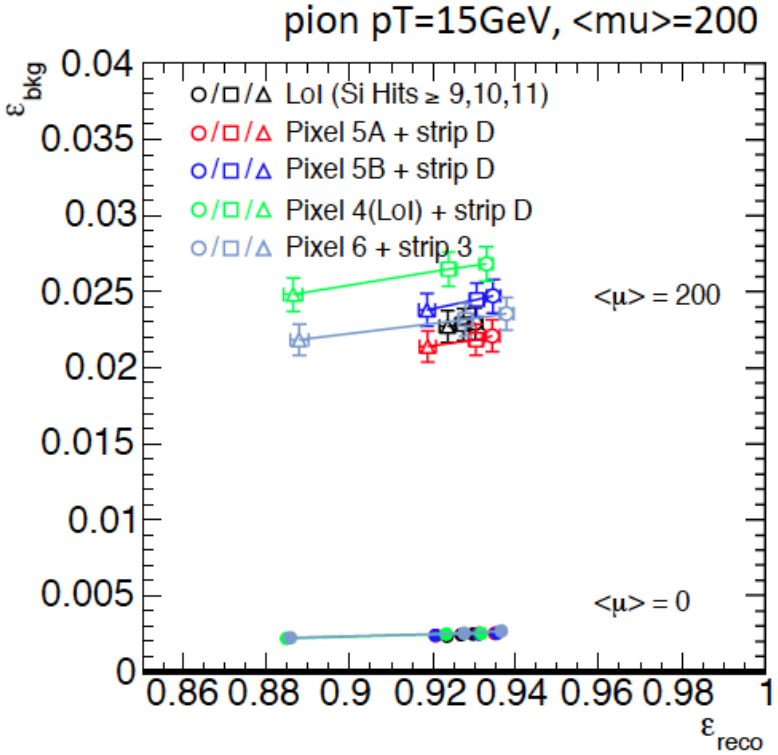
  R = 39, 75, 140, 220, 300 mm

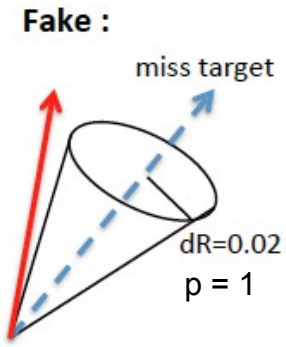
KEK

Number of pixel barrel layers

- Findings from first studies using single-particle samples at **<μ> = 200**:
  - Varying the **hit requirement** from 9 to 11 has little impact on fake rates
  - Primary track reconstruction efficiency improves with **more layers**, for same hit requirement
  - **Pileup** only increases the fake rate, no impact on the primary track efficiency
  - Doublets vs. equidistance: no difference in primary track efficiency,
    fake rate conclusion depends on signal process (?)



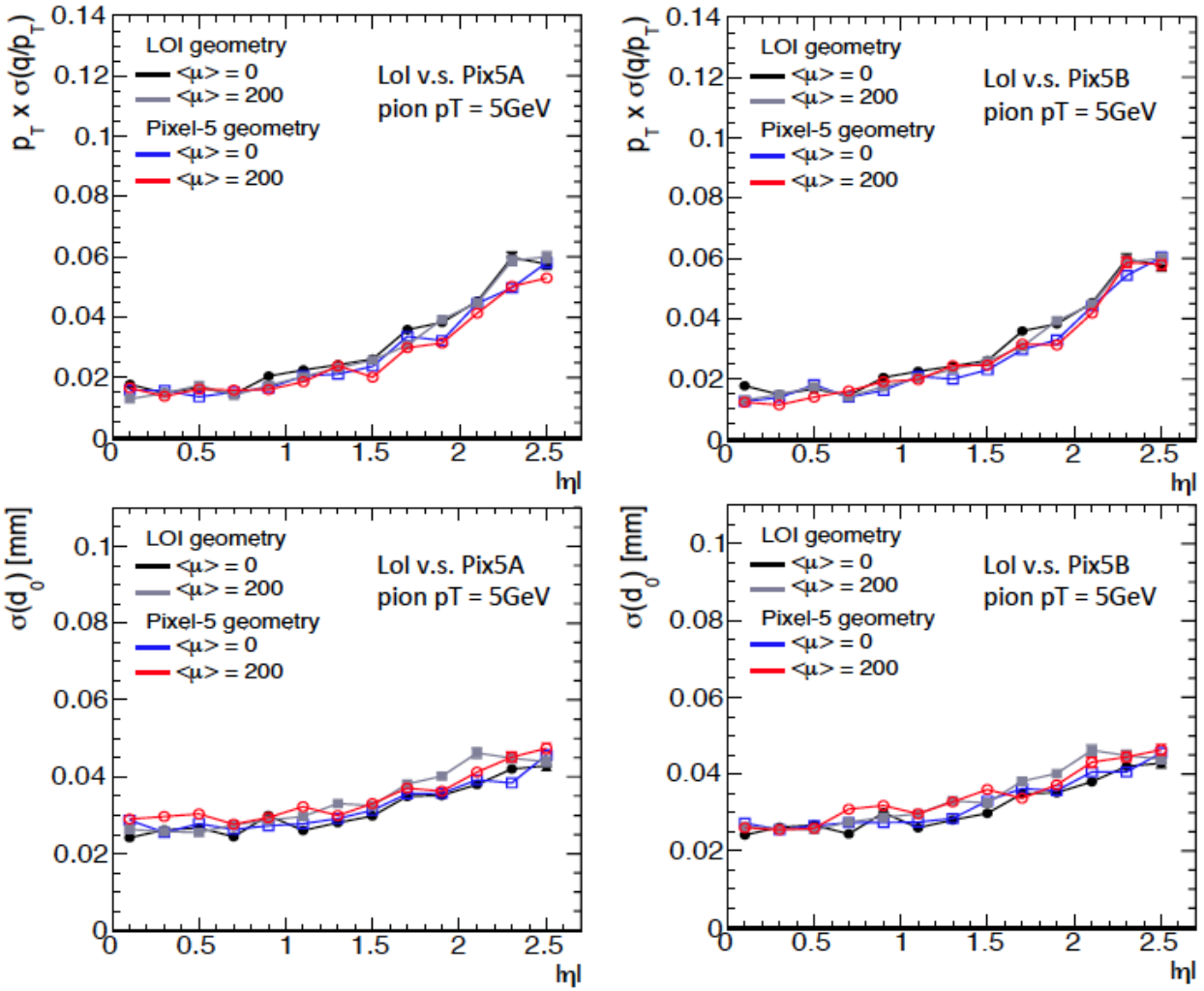




Number of pixel barrel layers

KEK

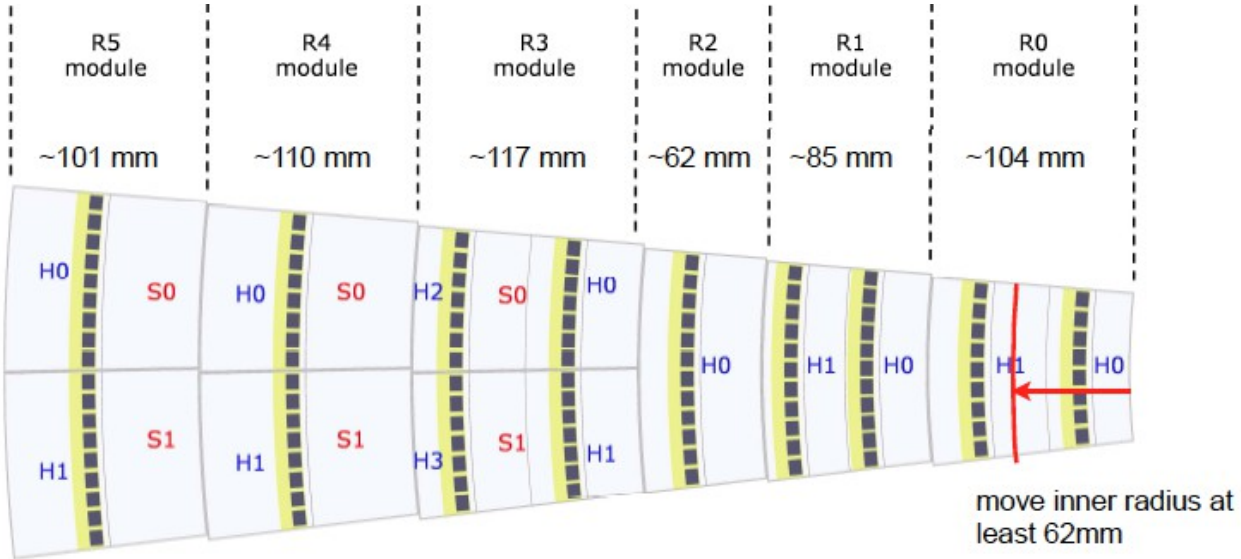
- Findings from first studies using single-particle samples at **<μ> = 200**:
  - Tracking resolution: Very little difference between layouts, and pileup conditions



Pixel volume discussion

Layout Task Force

- Proposal to increase the pixel detector radius to R ~ 395 mm
  - Would make room for an **eventual 6th pixel barrel layer**
  - Preliminary studies indicate no loss of coverage in forward region
- Arguments to keep the current baseline (boundary at R = 345 mm):
  - **Cost increase** from both the strip barrel and pixel endcap > savings from strip endcap
  - Might otherwise need to revisit the strip endcap **petal design**



(62 mm if removing R2, more otherwise)

Latest course of action:

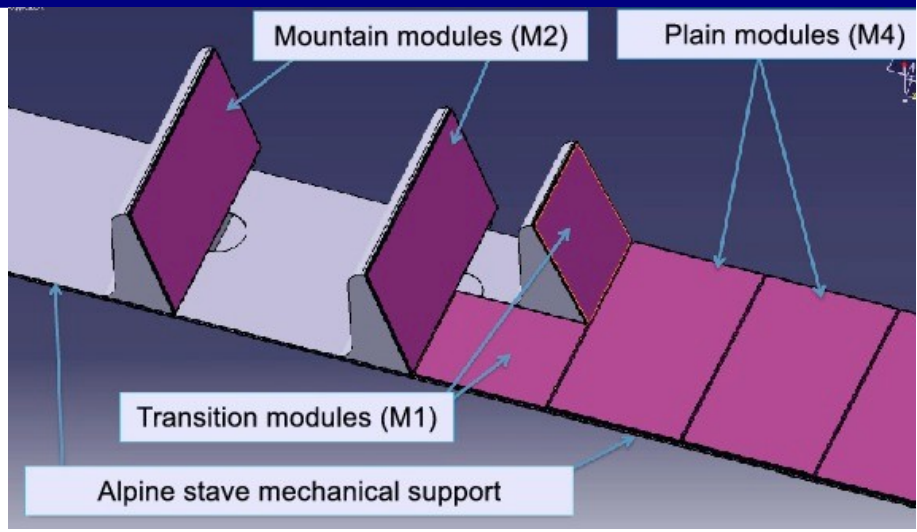
- Strips: Re-evaluate minimal clearance under current endcap petal design
- Pixels: Evaluate minimal additional radius needed for a 6th barrel layer

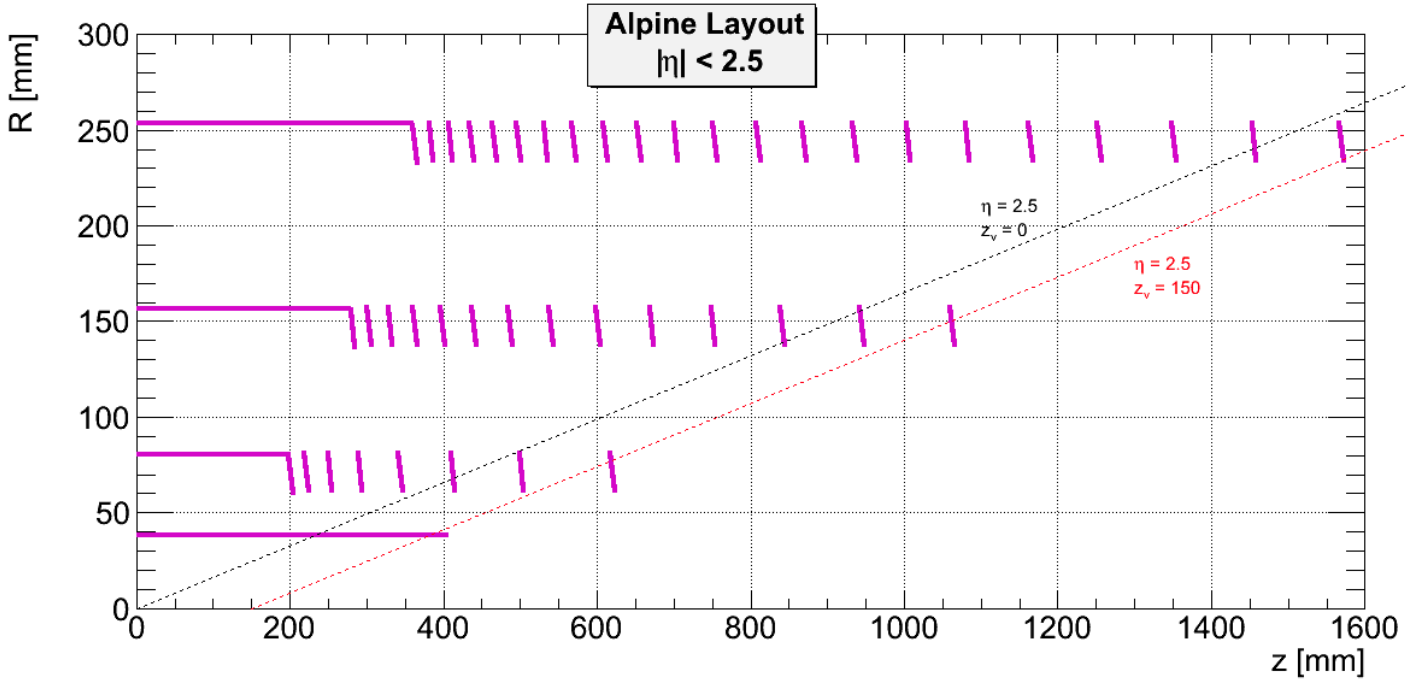
Specific design ideas

Inclined modules: Alpine layout

LAPP

- Proposal to **reduce the silicon area**
- Using inclined modules on barrel staves
- Currently implemented in **fast simulation**
  - Development of a tool to facilitate the transition to full simulation

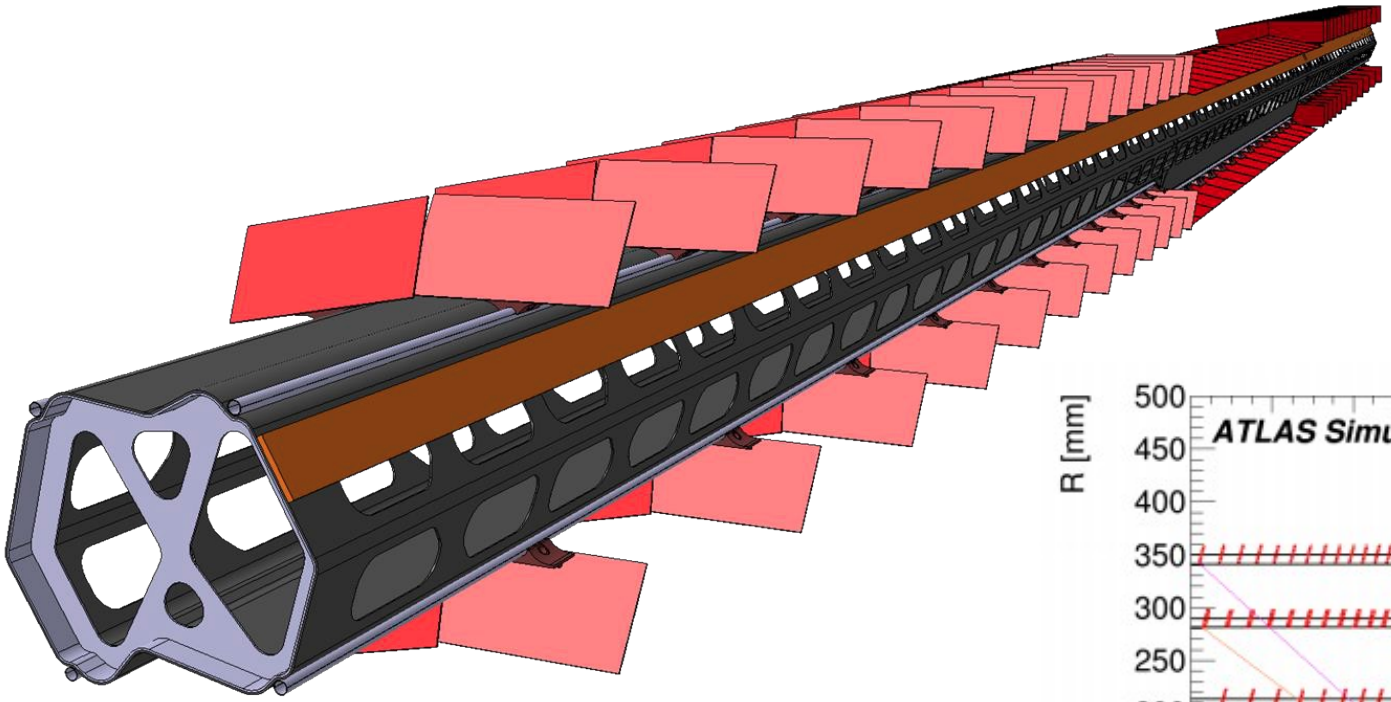


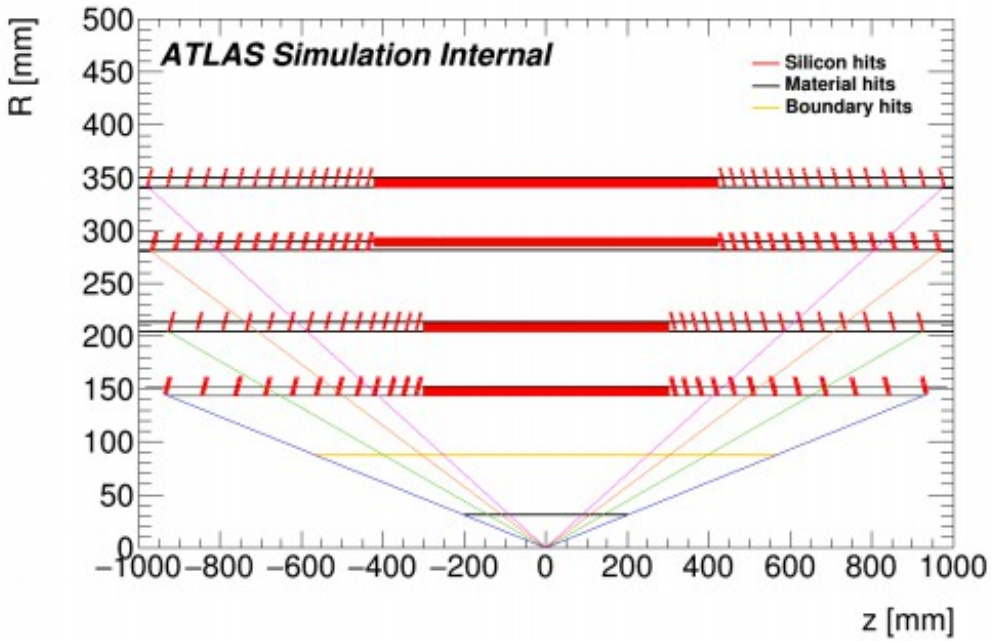


Inclined modules: SLIM layout

UniGe

- More recent support structure proposal for inclined modules
- Also now implemented in fast simulation

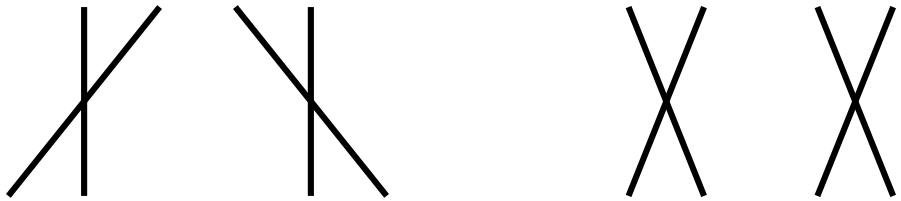




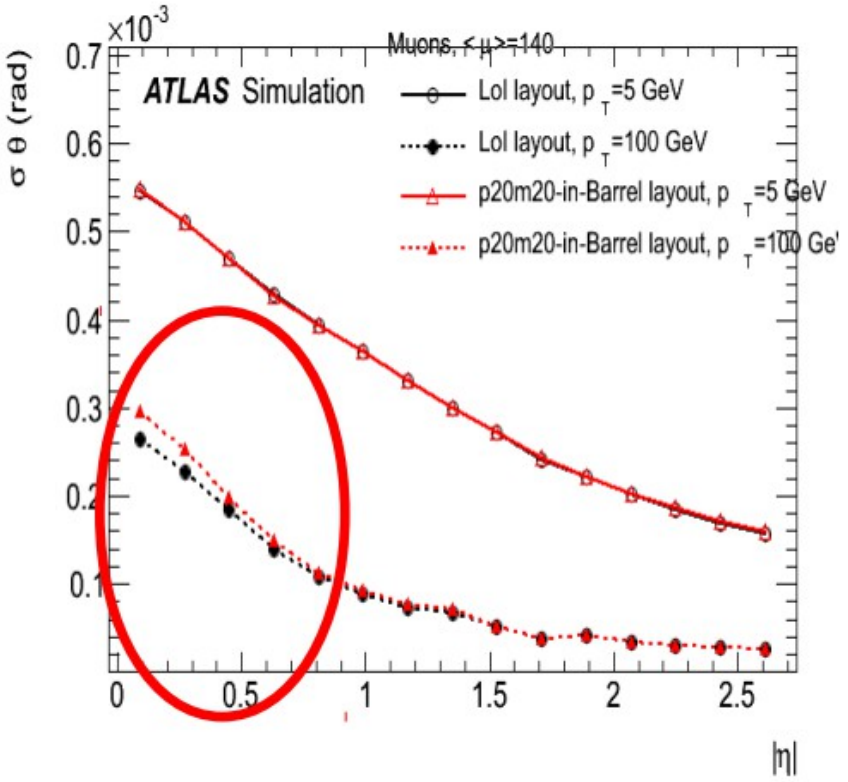
- Latest design is fully hermetic for z_0 displacement up to 150 mm

Strip stereo angle

- Nominal strip stereo design has alternating double-layers: 0 / 40, -40 / 0 mrad
- Investigation of the **θ resolution** using +20 / -20 mrad design
  - Arguably easier and cheaper to build
- First results: slightly better performance at high momentum with 0 / 40, -40 / 0
  - To be studied further

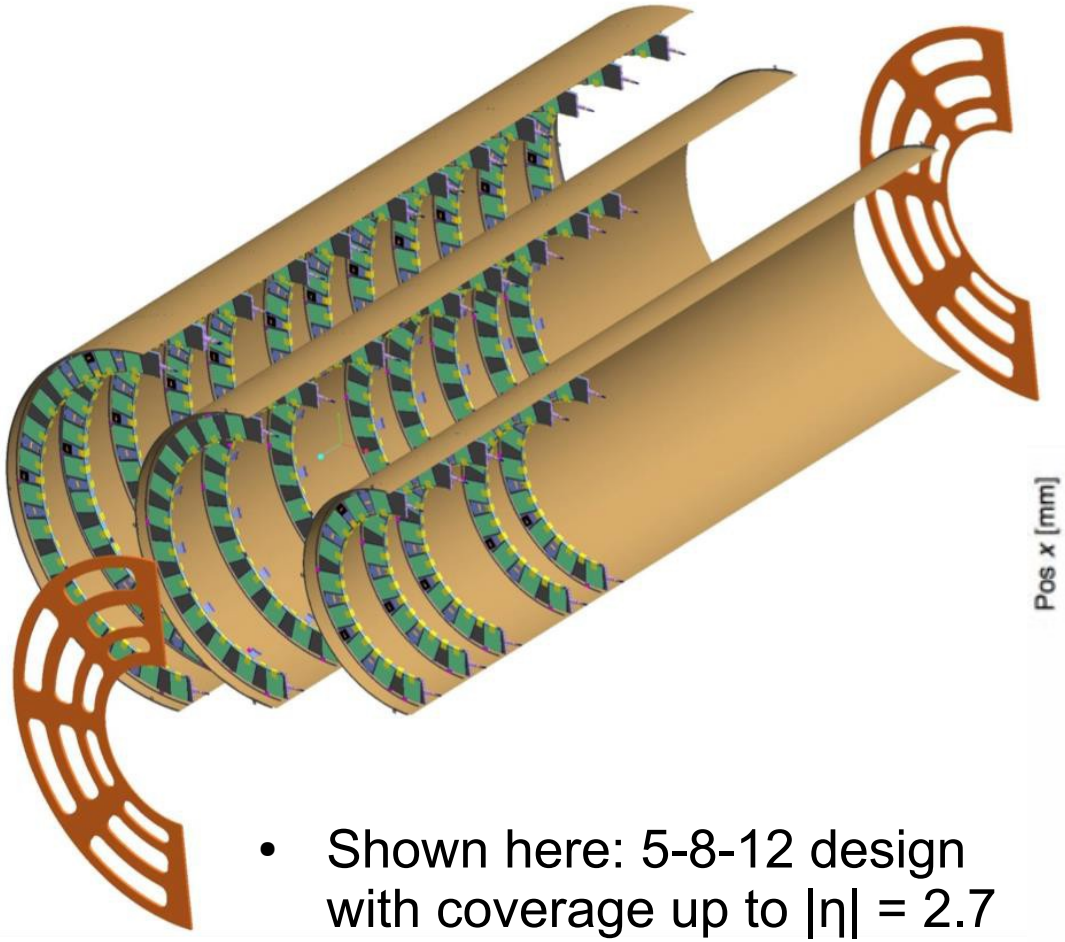


0 / 40, -40 / 0 **vs.** +20 / -20



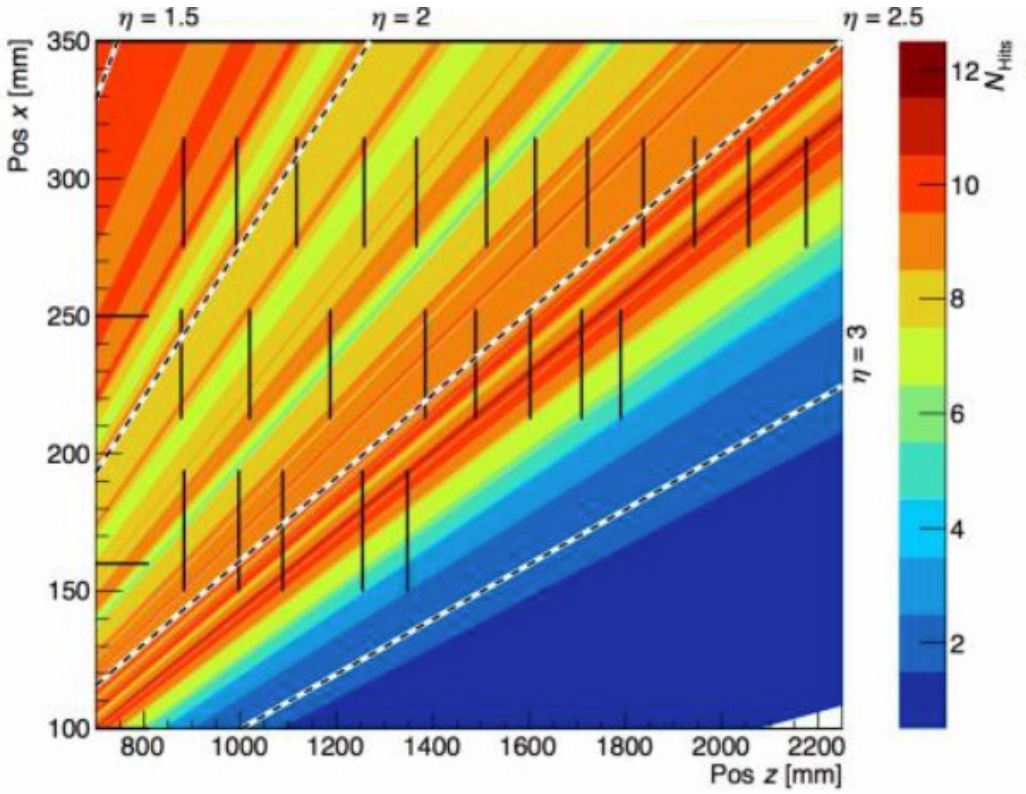
UK groups

Pixel endcap rings



- Realistic pixel endcap design with room for supports and services
- Quad module ring positions are individually adjustable

- Shown here: 5-8-12 design with coverage up to |η| = 2.7
- Hermetic when optimized
- Extendable to high η

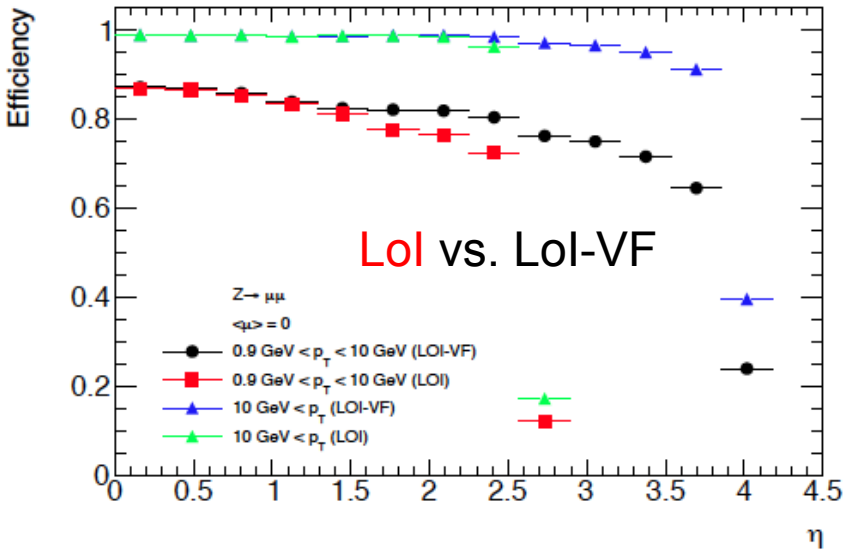


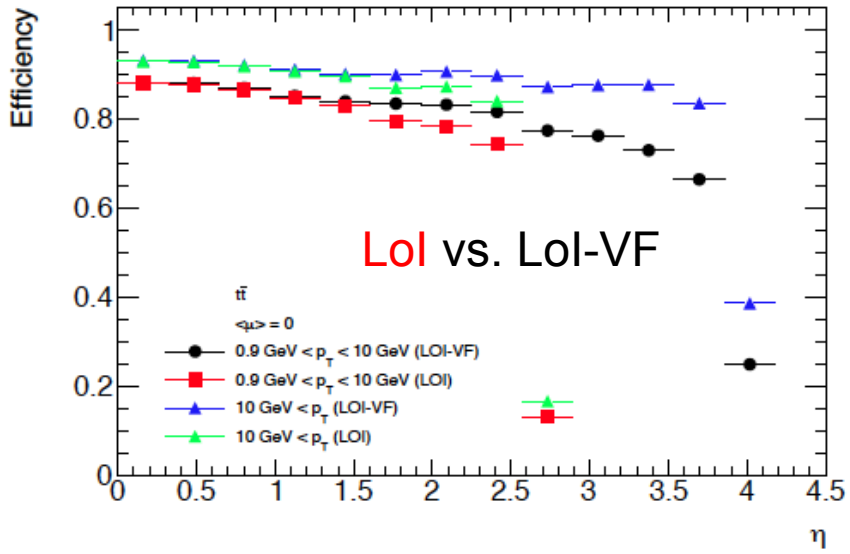
Extended tracking η coverage

Extended tracking η coverage

Large Eta Task Force

- Main benefits as demonstrated in the Large-η Task Force report:
  - Improved vertexing, **pileup jet suppression** by 95% with hard scatter jet eff. 80-85%
    - Results in improved **MET resolution** by about 30%
  - Forward **b-tagging**: 70% efficiency maintained, at expense of 5x mis-tag rate
  - Forward **electron** identification: fake rejection improves by factor 1.5
  - **Muon** acceptance increased by 30%, if combining extended ITk with muon tagger
  - Improved sensitivity and/or acceptance in VBS and VBF H studies, bbH, H → 4ℓ, etc.

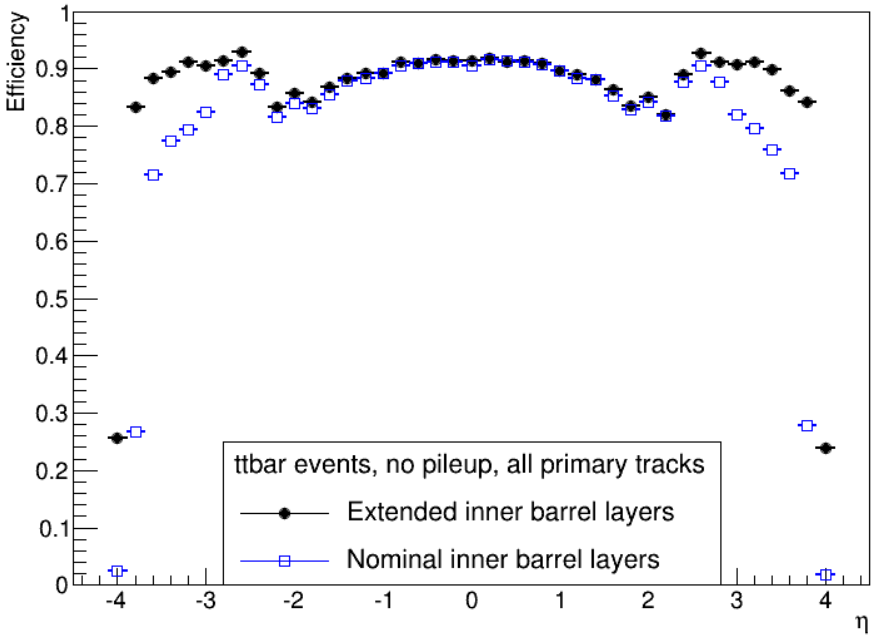


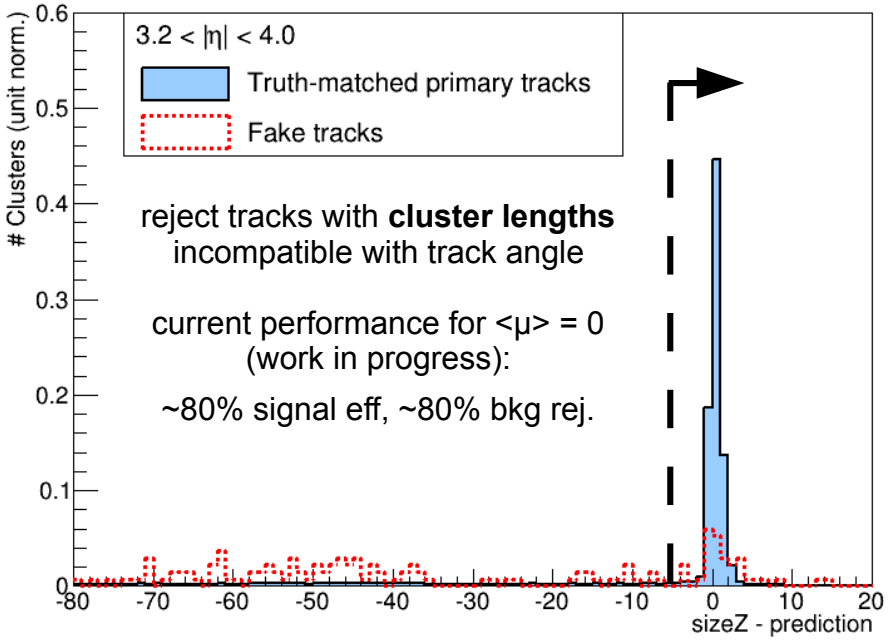


Extended inner pixel barrel

Wisconsin
LBNL

- In addition to extending the pixel endcap, **extending the inner pixel barrel to |η| = 4** is expected to bring significant gains in tracking performance
- Comparing layouts with a realistic pixel endcap, with and without barrel extension:
  - Reconstruction **efficiency** improved by 20% (absolute gain)
  - Track parameter **resolutions** improved by up to an **order of magnitude**
  - Potential to **reduce fake rates** using cluster length in the forward region





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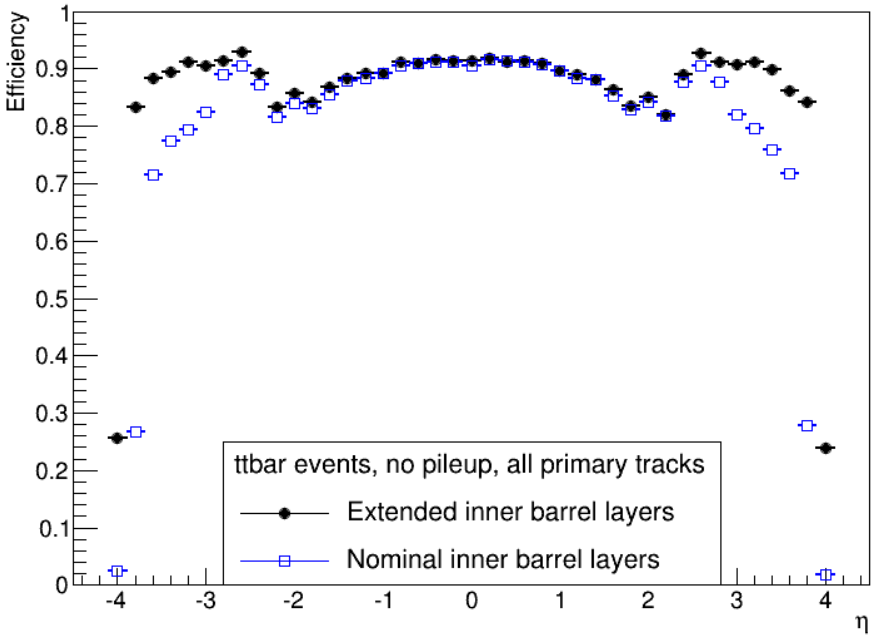
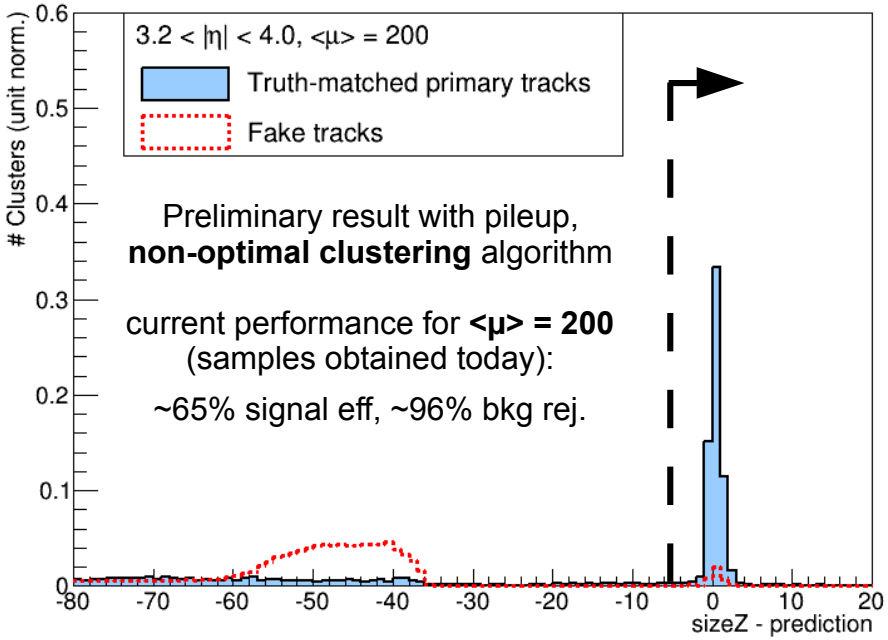
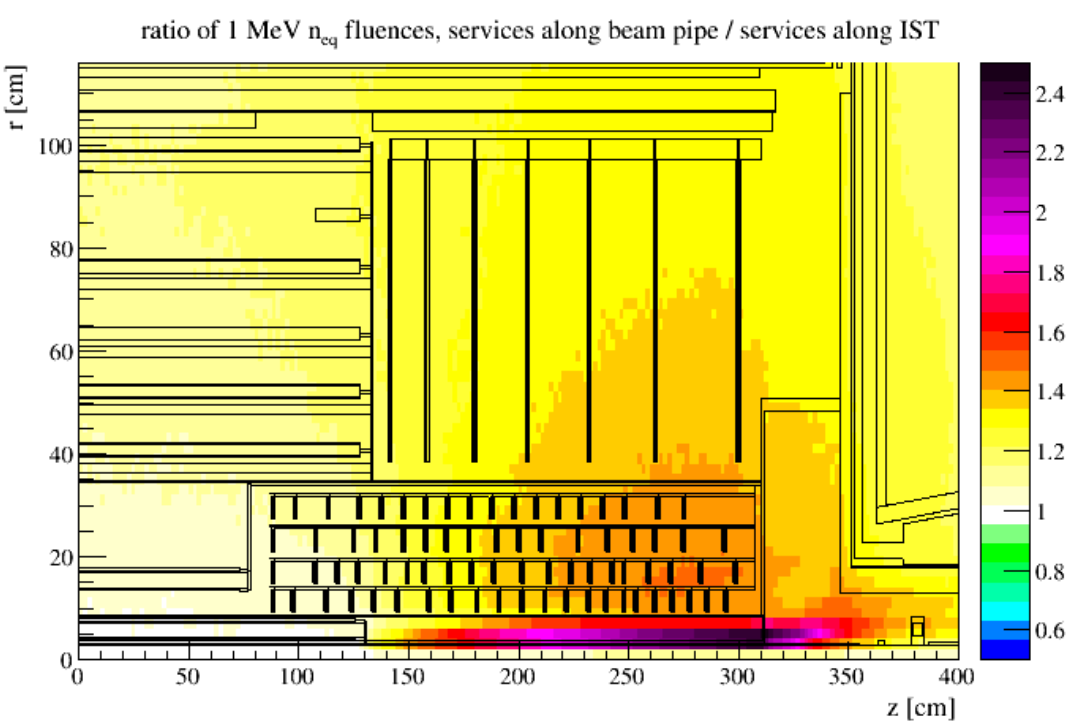
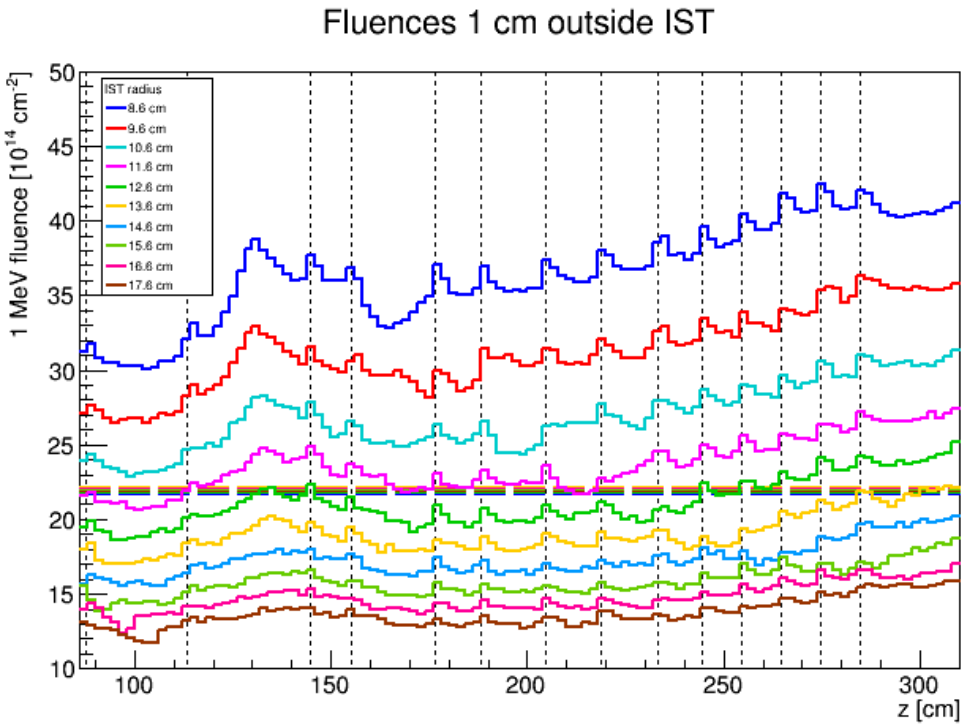




Fluence and dose studies

- Standalone **FLUKA model** of ITk used to study radiation backgrounds
- Compared fluences and doses for a variety of scenarios
  - In particular, radius of **inner pixel barrel services**
  - Conclusion: Need to route these services no lower than **R = 140 mm**





Very forward layout: Full simulation

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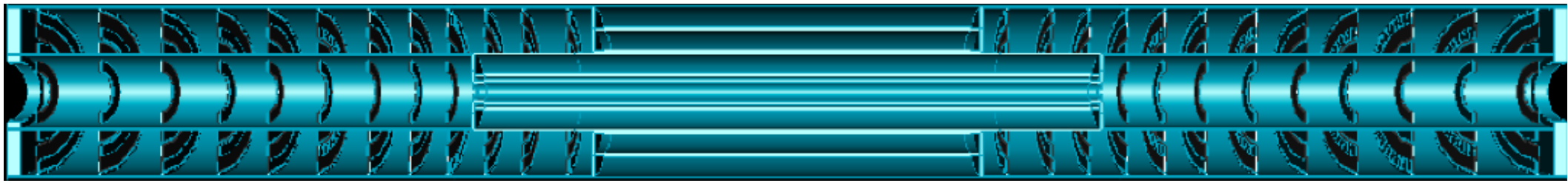
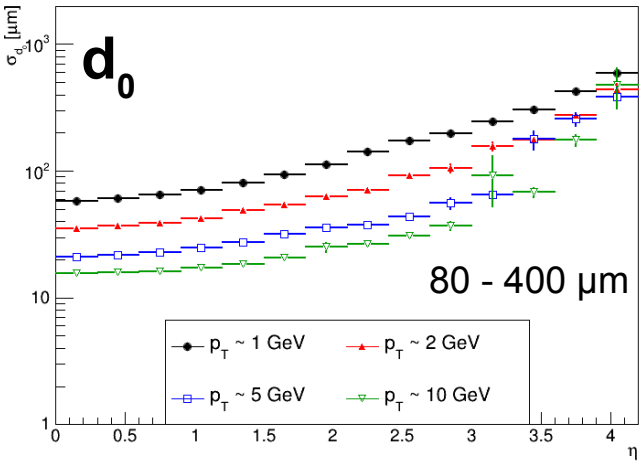
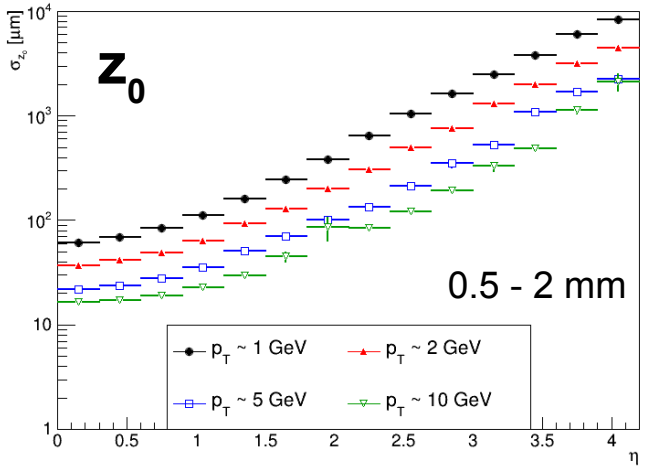
- Solution to keep coverage to |η| = 4: **Innermost pixel endcap rings inside the IST**
  - Replaceable along with inner barrel layers; allows to route inner barrel services above

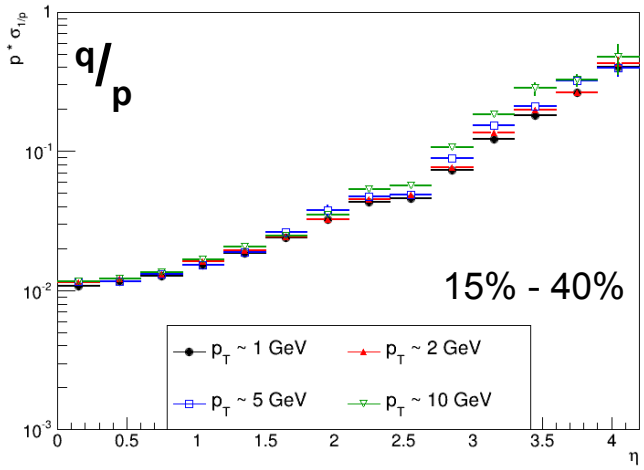


Critical effort from Swagato Banerjee

- **Best resolution so far** from a realistic layout → **now verified with pileup! <μ> = 200**





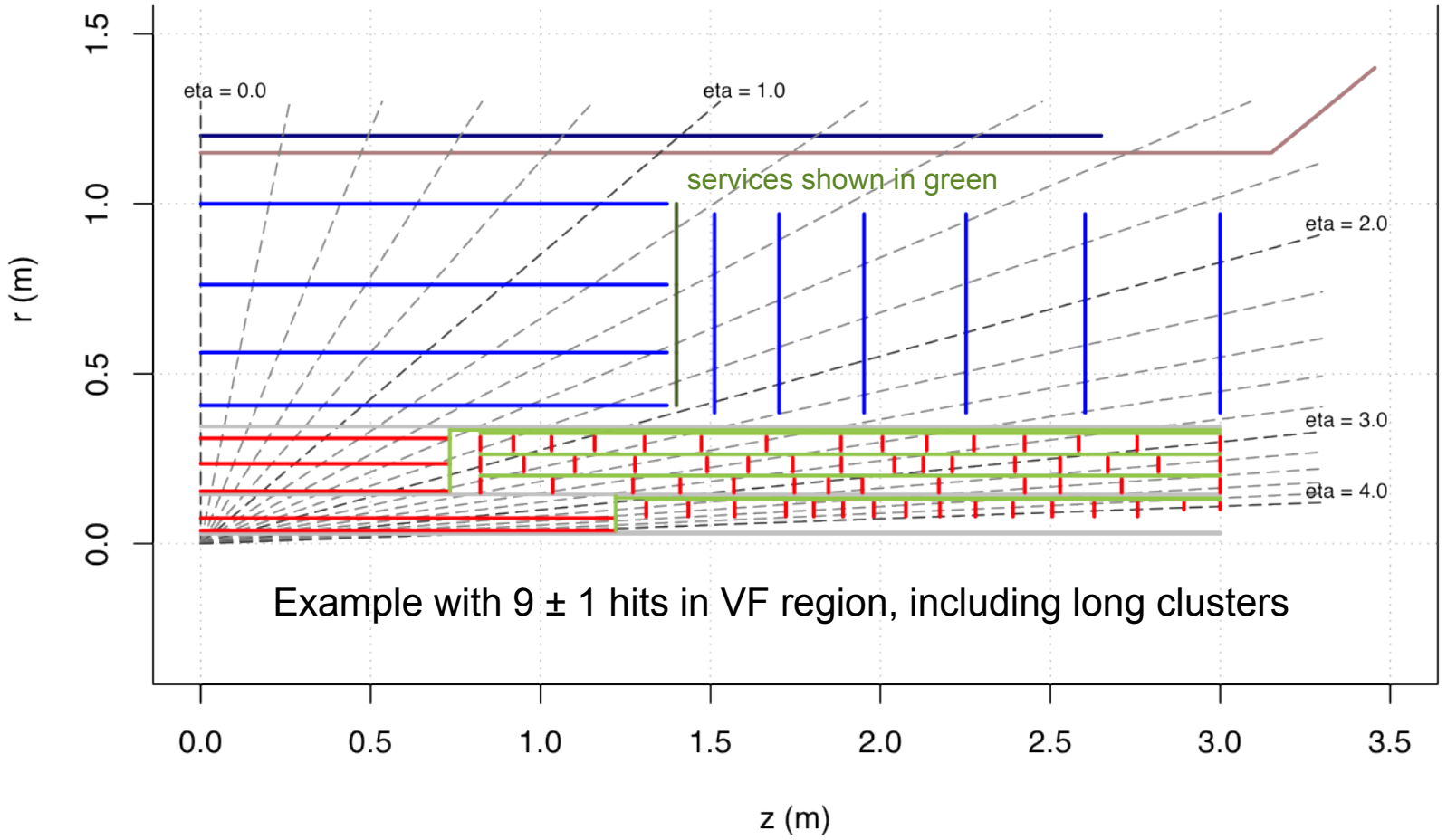


Numbers are for p_T ~ 5 GeV, **3.2 < |η| < 4.0**

Very forward layout: Latest design

CERN
Liverpool
LBNL

- Innermost pixel barrel layer extends to ± 1.22 m → **|η| < 4.0** (15 cm beam spot)
- Strip layout optimized with 14 barrel modules and 6 disks
- Pixel endcap ring positions optimized
  - Pixel radius at 345 mm shown here; can be increased if needed using more modules



Conclusion

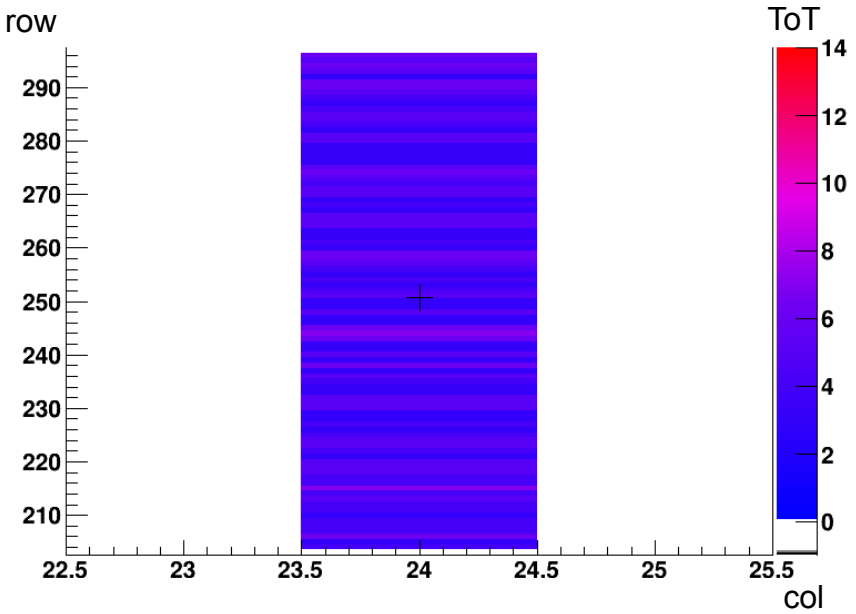
- The ITk layout is an optimization problem with **a lot of degrees of freedom**
  - We will have to **fix some of them first** to make progress
    - Phase-II upgrade budget → ITk share of it → |η| coverage
    - Pixel-strip boundary → Strip layout → Pixel layout
  - Reached consensus on some **general concepts**
    - Pixel: 5 to 6 barrel layers, 3 to 5 endcap ring layers
    - Strips: 4 double-sided barrel layers (no stub), 6 endcap disks
- The **requirements** document might help to converge, draft here
- Many important details need confirmation: **mechanics**, service routing, etc.
- Overall, very good expected **performance**
  - Including for the extension to **|η| = 4**
  - Many details yet to verify in samples with pileup at **<μ> = 200, now available!**

BONUS SLIDES

Long pixel clusters in data

Wisconsin
LBNL, SLAC

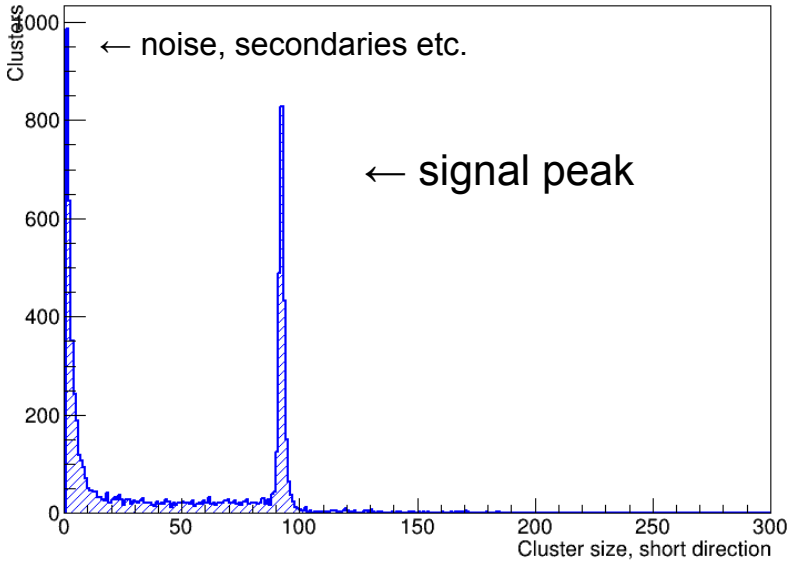
- Long pixel clusters observed in **data from IBL module** test beam at SLAC ESA

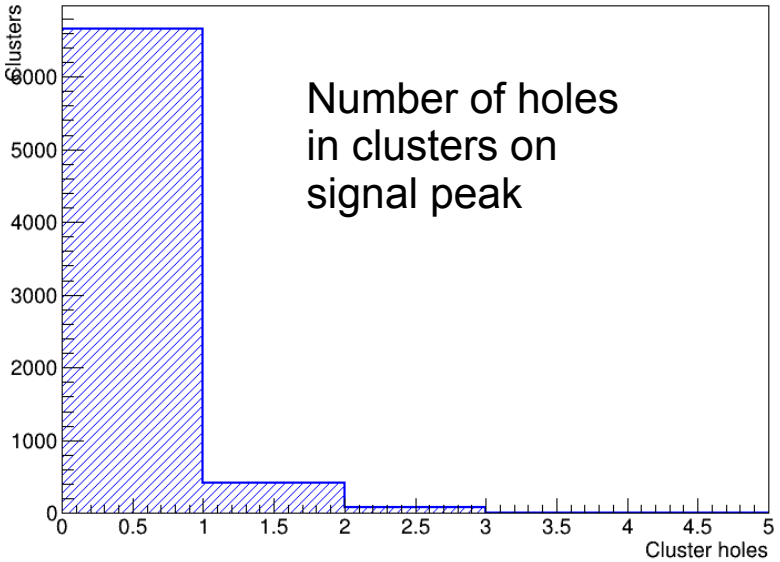


← Typical cluster for angle ~ 2.5 deg (η ~ 3.8), 10 GeV electron beam

IBL planar module, Threshold 1000e, beam in short pixel orientation

size = 93, no hole





Long pixel clusters in data

Wisconsin
LBNL, SLAC

- Long pixel clusters observed in **data from IBL module** test beam at SLAC ESA
- Cluster length → **precise measurement of the incidence angle**
  - In tracking context: measurement of θ → z_0 given R
- Will also study CERN test beam data, and IBL data